Potential of Partial Cutting Silvicultural Systems To Affect Stand Productivity and Wood Flow

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ABSTRACT

Clearcutting is the predominant silviculture system currently practiced throughout the Nelson Forest Region (62.7% of the area harvested), followed by seedtree (20.8%), single tree selection (6.7%), group selection (5.7%), and shelterwood (4.1%).

Recently completed Timber Supply Reviews indicate significant reductions in both short and long-term wood supply. Additional reductions are anticipated with the implementation of the Forest Practices Code (FPC) and the Kootenay Boundary Land Use Plan (KBLUP). These initiatives indicate that increased reliance on partial cutting systems will be necessary in order to meet biodiversity, visual quality and green-up management objectives while minimizing the wood flow reductions.

This report identifies "low risk" timber types, as well as general silvicultural and operational guidelines for various partial cutting silviculture systems that are applicable to this region. "Low risk" refers to biological suitability and high probability of regeneration success while minimizing the negative effects of *Armillaria* or other forest pathogens.

Uneven-aged group selection and even-aged patch clearcut and shelterwood systems are the most promising to meet a wide variety of management objectives. Current and regenerated stand structures can be manipulated to maintain or introduce more disease resistant species throughout the rotation.

Partial cutting growth curves for several common stand types were developed using the PROGNOSIS stand growth model. The effects on mean annual increment (MAI) of varying the time of first partial cutting entry, years to final harvest, residual basal area after partial cutting and two levels of *Armillaria* were identified.

A methodology for incorporating PROGNOSIS stand level partial cutting growth curves into the FSSIM harvest forecast model was successfully developed and the effects of partial cutting and *Armillaria* on harvest levels was then examined in Boundary and Cranbrook Forest Districts. The results varied between the two districts. In one District, partial cutting maintained short-term wood supply for a longer period of time, with little impact on the long-term wood supply, by addressing constraints imposed by the Forest Practices Code and the draft Kootenay Boundary Land Plan and providing greater flexibility in selecting stands for harvesting. However, when *Armillaria* was present, losses to the long run sustained yield increased with partial cutting.

A more balanced mixture of clearcutting and partial cutting silviculture systems is recommended. The choice of system is not limited to one of the classical models, but may include variants that take advantage of current stand conditions to meet management, biological and social objectives. An increase in the amount of area harvested annually in the Nelson Forest Region using low risk partial cutting silviculture systems is recommended.

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1 INTRODUCTION

Recent Timber Supply Reviews indicate significant reductions in both short and long term wood supply. Additional reductions are anticipated with the implementation of the Forest Practices Code (FPC) and the approved Kootenay Boundary Land Use Plan (KBLUP). The allowable annual cut (AAC) for the Nelson Forest Region has been reduced from 6.3 million to 5.5 million cubic meters per year, representing a loss of 13%. Implementation of the FPC and the KBLUP are anticipated to reduce the AAC to between 4.7 and 5.2 million cubic meters. Two major factors contributing to the reduction are green-up/adjacency rules and integrated resource management objectives such as biodiversity, wildlife habitat and visual quality. At present, the KBLUP Implementation Strategy Task Force is considering partial cutting tactics that could positively influence the wood flow in the region without negatively affecting the long run sustainable yield. It is speculated that partial cutting systems may be able to address these management factors and improve wood supply in the short term because of increased flexibility in harvest scheduling.

A recent study by Hawe (1996) shows that, between 1988 and 1995, clearcutting was the predominant silviculture system practiced throughout the Nelson Forest Region (approximately 62.7% of the area harvested). This was followed by seedtree (20.8%), single tree selection (6.7%), group selection (5.7%), and shelterwood (4.1%). The amount of each system employed varies greatly by district and licensee. Little partial cutting is done in Golden, Kootenay Lake and Revelstoke Forest Districts. Arrow, Boundary, Cranbrook and Invermere Forest Districts use a variety of silviculture systems, although the majority are low volume retention clearcutting and seedtree cuts. Even in similar forest types, some districts and licensees commonly use high volume retention partial cutting systems while adjacent districts rely on clearcutting (Hawe 1996).

The amount of partial cutting across the region depends on past experience with various systems, concerns about the effects of *Armillaria ostoyae* root disease impacts, and applicability of certain stand types (e.g., over mature, decadent cedar-hemlock) to systems other than clearcutting. Hawe (1996) concludes there is potential to increase the amount of partial cutting silviculture systems based on the wide variety forest types throughout the region.

Current FPC guidelines are quite broad in order to provide flexibility in management options. However, several guidebooks must often be consulted to provide basic guidance for choosing a partial cutting silvicultural system. Even then, guidebooks may not provide enough guidance to enable foresters to develop the most appropriate silviculture prescription for the site or estimate the impacts on stand level productivity of the prescriptions. For example, the *Green-up Guidebook* (B.C. Min. For. 1995a) states that green-up does not apply to shelterwood, single tree, group selection and other uneven-aged systems where 40% or more of the pre-harvest basal area has been retained. The *Silviculture Systems Guidebook* (B.C. Min. For. 1995b) is not specific to the stand, timber type or biogeoclimatic level (B.C. Min. For. 1995b). The *Root Disease Management Guidebook* (B.C. Min. For. 1995c) states that partial cutting or commercial thinning of any infected stand should be carefully reviewed but gives no specifics. This guidebook discusses species susceptibility and general operational strategies to minimize risk of root disease, but not from a broad silviculture systems or ecologically-specific perspective.

Successful management requires that the major *Armillaria* root disease problems and risks be identified at the stand level, and that subsequent silviculture prescriptions attempt to reduce or avoid future volume losses.

The currently-used stand growth models TASS (Tree and Stand Simulation) and its abbreviated version, WinTIPSY (Table Interpolation Program for Stand Yields using Microsoft Windows) (Mitchell et al. 1995) were developed by the B. C. Ministry of Forests Research Branch. These models were not designed to model: 1) mixed species stand types that are common in the Nelson Forest Region; 2) the effects of *Armillaria*; or 3) partial cutting. Efforts to incorporate these effects in TASS or WinTIPSY are makeshift at best. The only stand growth model that is currently available for modelling all these parameters is PROGNOSIS (Stage 1973), which has recently been renamed the Forest Vegetation Simulator (FVS). A calibrated version of PROGNOSIS for British Columbia is expected by April 1998.

The final choice of silviculture system depends on management objectives, silvicultural characteristics (such as genetic variability, shade tolerance, seed production, associated pests, etc.) of the species, the intrinsic characteristics of the silvicultural systems (such as stand structure), and our experience in managing the species. Current unmanaged stands may be over- or under-stocked, have varying proportions of mature trees, desirable advanced growth and mixtures of species. Because of these factors, there will be considerable variability in the nature of the first entry, which may not be readily recognizable as the first entry of a classical silviculture system. The choice of system is not limited to one of the classical models, but may include variants that take advantage of current stand conditions to meet various management, biological and social objectives (Helms and Lotan 1988).

Within the framework of these nonspecific guidelines and an absence of functional growth and yield models, partial cutting is still expected to dramatically increase over the next few years. The goal of this paper is to provide some guidance for implementing this increase without undue risk of disease, regeneration failure and loss of MAI.

2 OBJECTIVES

Given the recent increases in partial cutting prescriptions to deal with the various aspects of the Forest Practices Code and the Kootenay Boundary Land Use Plan, it is necessary to examine which partial cutting systems are sustainable in an *Armillaria* environment, what yields are expected and what impacts these practices will have on wood supply.

The specific objectives of this report are:

1. to identify "low risk" timber types and stand conditions for partial cutting silviculture systems;

2. to evaluate the effects of various partial cutting regimes and levels of *Armillaria* on stand productivity;

3. to provide general partial cutting guidelines and management strategies for both silviculturists and modellers; and

4. to evaluate the effects of partial cutting "low risk" timber types on wood flow in Boundary and Cranbrook Forest Districts.

The "low risk" refers to biological suitability and high probability of harvesting and regeneration success while minimizing the negative effects of *Armillaria* root disease.

For the purposes of this report, partial cutting silviculture systems will include seed tree, shelterwood, and selection systems. Patch clearcuts can be used synonymously with group selection because of their nature. Commercial thinning, although not a silvicultural system, is included in this report because it can be incorporated into various partial cutting systems as a preparatory cut.

3 METHODOLOGY

The identification of low risk timber type/BEC (Biogeoclimatic Ecological Classification) subzone combinations is based on a selective literature review of silviculture systems and discussions with various Forest Service staff, licensees, and United States Forest Service (USFS) foresters. Forest Service and licensee staff within the region provided input during the production of the historical review of partial cutting practices in the Nelson Forest Region (Hawe 1996). The USFS foresters provided their input during interviews and field trips made by the author to the Okanogan and Colville National Forests in Washington State and the Priest River Experimental Forest in Idaho between April and September 1996. The USFS foresters included John Townsley (Okanogan National Forest), Jay Berube (Colville National Forest), as well as Russell Graham and Theresa Jain (Priest River Experimental Forest). Jim Smith, a local consulting forester, also provided input based on his many years of experience as the Small Business forester in the Vernon Forest District.

The Boundary and Cranbrook Forest Districts were selected for analysis because:

1. The BEC subzones most closely correlated with the Daubenmire habitat types used in the Inland Empire version of the PROGNOSIS stand growth model used to develop the partial cutting growth curves; and

2. Permanent and temporary sample plot data were available for the timber type/BEC subzone combinations that occurred within those districts.

The preliminary low risk timber types that were identified included Douglas-fir, western larch, lodgepole pine and ponderosa pine. The timber type/BEC subzone combinations that represented the largest area within each District were then selected for analysis. These combinations included:

Boundary	ICHmk1	Pl pure	G/M, P sites
	ICHmw2	Lw pure	G/M, P sites
	IDFdm1	FdLw	G/M, P sites
	IDFdm1	PlFd	G/M, P sites
	MSdm1	PlFd	G/M, P sites
	MSdm1	Pl pure	G/M, P sites
Cranbrook	ESSFdk	Pl pure	G/M, P sites
	IDFdm2	FdLw	G/M, P sites
	IDFdm2	FdPy	G/M, P sites
	IDFdm2	Pl pure	G/M, P sites
	MSdk	Pl pure	G/M, P sites
	MSdk	PlFd	G/M, P sites

Once the twenty-four timber type/BEC combinations were identified, operational inventory data was summarized to produce average tree lists for each of the combinations. Permanent (PSP)

and temporary (TSP) sample plots were reviewed to identify plots with tree lists similar to the inventory average. Tree lists that were similar to the inventory averages were selected to develop the PROGNOSIS growth curves. Where no similar tree lists were identified, average inventory tree species composition and site indices provided the basis for stands which would be grown from bare ground conditions using PROGNOSIS. A description of the stand composition and characteristics used for the analysis is detailed in Robinson *et al.* (1996).

ESSA Technologies Ltd. developed the growth curves for both clearcutting and partial cutting scenarios using PROGNOSIS (version 1.0f). Although this version is not yet calibrated for British Columbia, the self-calibrating features of the model allow reasonable projections that are sensitive to partial cutting, ingrowth and root disease (Robinson *et al.* 1996). Volume/age curves were developed for unmanaged stands using PSP and TSP measurement data where available, or from bare ground conditions using the model's built-in volume - age projection functions. These PROGNOSIS-developed growth curves were then adjusted to correspond to the appropriate VDYP (Variable Density Yield Projection) curves. The adjustments were based on one-cycle projections to find growth modifier factors for each species. As well, the projections were used as an iterative approach to identify a good fit to comparable VDYP runs (Robinson *et al.* 1996).

Various partial cutting management regimes were then assigned to the timber type/BEC subzone combinations (Table 1), and their resulting volume-age curves were developed. The partial cutting regimes favoured the retention of the larger, dominant, most *Armillaria* resistant species where possible.

A sensitivity analysis of the effects of partial cutting management regimes and levels of *Armillaria* infection on MAI was conducted and is described in detail in Robinson *et al.* (1996). A subset of four "low risk" timber type/BEC subzone combinations, on good and medium sites within the Boundary and Cranbrook Forest Districts, was selected. Three basic management regimes that reflect various levels of partial cutting constraints were examined. The first regime had no restrictions on basal area removal. The second regime had a 70% residual basal area retention requirement to simulate the effect of biodiversity constraints. The third regime had a 40% basal area retention requirement to simulate green-up constraints. For each of the three regimes, the effects of first entry age, years to final harvest after the first harvest entry, residual basal area after the first harvest entry and level of *Armillaria* infection at time of the first harvesting entry were examined (Table 2). The effects of *Armillaria* infection was modelled, with input from Don Norris (regional forest pathologist), using the ROTSIM root disease extension module for PROGNOSIS.

Tablecurve 3D automated surface fitting software (Jandel Scientific 1993) was used to analyze the results of all the various combinations of management regimes and *Armillaria* levels. Each combination spanned two rotations and the MAI was averaged for both rotations. An EXCEL ranking scheme was then used to select the ten combinations that produced the highest MAI over two rotations.

Table 1. Management regimes used in the development of partial cutting growth curves. Adapted from Robinson *et al.* (1996).

Timber type regardless of BEC subzone	Rotation	Species %	Stems/ ha	Target spacing at 15 yrs stems/ha	Partial harvest species rule	Age at partial harvest entry	Basal area removed %	Years delay from partial harvest entry to final harvest	Ingrowth after partial harvest entry species, stems/ha
FdLw G,M,P	1st	See Note 1	2000		Lw last	40-180 (in 10 yr steps)	0-100 (in 10% steps)	20-60 (in 10 yr steps)	Fd 1000 Lw 100
FdLwPy G,M,P	2nd	Fd 40 Lw 40 Py 20	3000	1200	Lw. Py last	70	60	20	Fd 100 Lw 100 Py 100
FdPy G,M,P	1st	See Note 1	2000		Py last	40-180 (in 10 yr steps)	0-100 (in 10% steps)	20-60 (in 10 yr steps)	Fd 1000 Py 100
FdPyLw G,M,P	2nd	Fd 40 Py 40 Lw 20	3000	1200	Lw. Py last	70	60	20	Fd 100 Lw 100 Py 100
FdPl & PlFd G,M,P	1st	See Note 1	2000		Pl first	40-180 (in 10 yr steps)	0-100 (in 10% steps)	20-60 (in 10 yr steps)	Fd 1000
FdPlPyLw G,M,P	2nd	Fd 55 Pl 25 Lw 10 Py 10	3000	1200	Pl first	70	60	20	Fd 100 Lw 100
Pl pure G,M,P	1st	See Note 1	2000		any	40-180 (in 10 yr steps)	0-100 (in 10% steps)	20-60 (in 10 yr steps)	none
PlFdPy G,M,P	2nd	Pl 60 Fd 20 Py 20	3000	1200	Fd first	60	40	20	none
Lw pure G,M,P	1st	See Note 1	2000		Fd first	40-180 (in 10 yr steps)	0-100 (in 10% steps)	20-60 (in 10 yr steps)	Fd 1000 Py 100
Lw pure G,M,P	2nd	Lw 80 Fd 10 Py5 Pl 10	1000	900	Fd first	60	60	20	

Note 1. The initial species composition of the first rotation stands varies by district and is based on observed stand composition for the timber type/BEC combination or the inventory average composition used to develop the bare ground simulations.

Table 2. Management regimes and *Armillaria* levels used to determine the effects of partial cutting on MAI.

BEC subzone/timber type combination	Management factor	Management Regime		
		No restrictions on harvesting practices	Harvesting practices to meet biodiversity requirements	Harvesting practices to meet green-up constraints.
<u>Boundary District</u> ICHmw2/Lw pure, MSdm1/PlFd and <u>Cranbrook District</u> IDFdm2/FdLw, MSdk/Pl pure	Residual Basal Area (m^2/ha)	0-100% in 10% increments, no restrictions on basal area retained	70% residual basal area retained	40% residual basal area retained
	Age at first partial cutting entry (yr)	40-180 in 10 yr increments	40-180 in 10 yr increments	40-180 in 10 yr increments
	Years from first partial cutting entry to final harvest entry	20-60 in 10 yr increments	20-60 in 10 yr increments	20-60 in 10 yr increments
	Armillaria infection level and % trees infected at first partial cutting entry	None - 0 Light - 7-25 Moderate - 13-54 *	None - 0 Light - 7-25 Moderate - 13-54 *	None - 0 Light - 7-25 Moderate - 13-54 *

**Note*: The light and moderate infection levels varied by species. Differences in *Armillaria* infection levels shown in the table are due to species-dependent differences in the time required for an individual tree to succumb to root disease and by differences in the ability of the species to resist the initial infection (Robinson *et al.* 1996).

To determine the effects of partial cutting on wood flow, the volume and yield summary information generated by PROGNOSIS was first converted to volume-age curves and related support files that could be used in the FSSIM harvest forecasting model. The conversion process is detailed in Robinson *et al.* (1996).

The original even-aged VDYP volume-age curves, used in the Timber Supply Review, for the timber type/BEC subzone combinations listed in Table 1, were replaced with partial cutting growth curves developed using PROGNOSIS. For some combinations, in Boundary Forest District, the PROGNOSIS-developed growth curves could not be precisely fitted to the original VDYP curves. Where this occurred, the PROGNOSIS-developed curves were scaled to have the same volume at age 120 as the VDYP curve for their unmanaged, first-rotation counterparts prior to superimposing different management regimes.

The present version of FSSIM (Version 2.1) is unable to model all the complexities of partial cutting and to perform a sensitivity analysis for the effects of all the partial cutting management regimes that were available. Therefore, only one partial cutting management regime was selected to examine partial cutting effects on wood flow for both districts. The partial cutting regime removed 40% of the basal area at age 100 with the remainder removed twenty years later. This regime was selected because it represents the highest basal area removal allowed to meet adjacency/green-up constraints imposed by the Forest Practices Code and reflects the anticipated age at which the partial cutting entry would be possible in unmanaged stands. This regime was applied uniformly across the six timber type/BEC combinations per district for which partial cutting growth curves were developed. It is recognized that other management regimes may produce different results.

4 RESULTS AND DISCUSSION

4.1 Effects Of Partial Cutting and *Armillaria* Levels On Stand Productivity

A partial literature review (Appendix A) as well as interviews with foresters confirm that some partial cutting silviculture systems and prescriptions may be more biologically suitable than others given certain stand conditions. However, the literature indicates the suitability only in general terms or with respect to very specific stand conditions and research objectives. Consequently the results are sometimes contradictory. Therefore, site specific prescriptions that maximize MAI cannot be developed from the results in Appendix A. However, the literature does show that group selection is suitable under the widest range of species and stand conditions.

The results in Appendix A can be used with the stand level sensitivity analyses in this report to plan low risk partial cutting prescriptions that maximize MAI when retaining different residual basal areas. For example, Appendix A provides guidance for choosing a particular silviculture system or initial residual basal area. The stand level sensitivity analysis can then be used to fine tune the basal area retention and demonstrate the impacts of the prescribed residual basal area on stand level productivity. When using the information provided in this document, it is important to remember that the final selection of a silviculture system, harvesting regime or residual basal area must be based on specific stand characteristics and management objectives and not general guidelines.

With high non-timber value pressures, it is inevitable that some residual trees will be prescribed. The seed tree and shelterwood silviculture systems are becoming common where non-timber values are being emphasized (Vyse *et al.* 1991). The number of residual trees depends on resource management objectives, stand constraints, site limiting factors, and silvicultural characteristics of the species. Therefore, seed tree and shelterwood systems can appear similar on the ground. The group selection (and small patch clearcut systems) shows the most promise for meeting many of the management constraints and forest health requirements. Becker (1995) indicates its suitability to address stands with a predominance of climax species as well as current and future *Armillaria*, spruce budworm, bark beetle and dwarf mistletoe concerns. Other advantages of the group selection system include the ability to harvest root rot centres, easily employ root removal techniques and manage for more *Armillaria*-resistant species. From a layout and planning perspective, this is one of the easiest partial cutting systems to apply as it more closely resembles clearcutting (Smith and Smith 1994).

Our stand level sensitivity analysis, showing management regimes and trends that produced the highest MAI over two rotations, is summarized in Table 3. Because PROGNOSIS is not yet calibrated for British Columbia, the results should be viewed in terms of comparative trends, and the MAI figures should not be considered absolute values. A re-analysis with the calibrated version may increase the precision of the results.

Maximum MAI varied considerably with stand type, first entry age, residual basal area, years to clearcut after the first entry and level of Armillaria. The results indicate that there are residual basal area/maximum MAI combination thresholds where one silviculture system may be preferable over another. Therefore, generic partial cutting prescriptions for all the stand types are not appropriate and they may result in loss of productivity.

Partial cutting, modeled as a thinning from below by PROGNOSIS, produced slightly higher MAIs than clearcutting, except in larch stands. For larch stands, clearcutting and partial cutting systems leaving a light residual basal area (i.e. group selection, or seed tree) appear to produce the highest MAI. The modelling assumed that all the residual timber will be removed in the final harvest, therefore, no deductions for non-recoverable losses due to other management objectives could be reliably forecast. Also, improper choice of residual basal area or timing of harvest entries can significantly reduce the MAIs below those of clearcut systems.

The highest MAI was obtained when the initial partial cutting entry was in younger stands. Commercial thinning may, therefore, be a viable option when prescribing a management regime that maximizes productivity.

As predicted by PROGNOSIS, non-timber management objectives, such as biodiversity and adjacency, may be achieved with little or no loss in productivity through partial cutting or commercial thinning. Both the biodiversity requirement of 70% residual basal area (RBA) and the adjacency requirement of 40% RBA were within the range of retention that produced the highest MAI over two rotations in all the stand types except pure larch. The 40% RBA resulted in a lower MAI than that of clearcutting or leaving 70% RBA. However, these MAI losses were small, ranging from 2-5%.

There is a tradeoff between maximizing stand productivity and harvesting the residual volume as soon as adjacency constraints are met. Our analysis indicates that in order to maximize MAI, the final harvest entry should be long after the regeneration would typically be established in clearcut, seed tree or shelterwood systems. Additionally, the time to reach minimum green-up and adjacency standards (approximately 20 years) is considerably shorter than the twenty to sixty years between the first and final entries that maximize MAI.

The effects of leaving the overstory for such long periods were not examined, however, if residual trees are left on-site over a large portion of the rotation, then their competitive influence on the developing regeneration and management objectives must be considered (B.C. Min. For. 1992). For the seedtree system, the residual basal area of most seed tree systems is too low to meet the Forest Practices Code guidelines in areas where clearcutting is constrained because of adjacency rules. Additionally, MAI can be reduced up to 20% if the residual volume is not harvested (Vyse *et al.* 1991). For the shelterwood system, if heavy residual basal areas are retained for a long period of time, natural regeneration of more *Armillaria*-susceptible, shade tolerant species is favoured. This may not meet the short or long-term management objectives in *Armillaria*-infected stands. In the short-term, the disease may spread faster, and in the long-term, it will take longer to meet green-up requirements.

Table 3. Partial cutting regimes that maximize MAI by stand type and *Armillaria* level as determined by PROGNOSIS.

Stand Type	*Armillaria* Rate	Unrestricted Residual Basal Area (RBA)				70% RBA				40% RBA			
		First Entry Age (Years)	Residual Basal Area	Years to Clearcut	MAI (m^3/ha/year) over 2 rotations	First Entry Age (Years)	Residual Basal Area	Years to Clearcut	MAI (m^3/ha/year) over 2 rotations	First Entry Age (Years)	Residual Basal Area	Years to Clearcut	MAI (m^3/ha/year) over 2 rotations
Pl Pure G.M Site MSdk	None	40-60	50%-80%	20-40	2.59-2.63	As Per Unrestricted				50-70	40%	20-40	2.48-2.57
	Light	40-60	70%-90%	20-30	2.39-2.44	As Per Unrestricted				40-60	40%	20-40	2.24-2.38
	Moderate	40-50	70%-90%	20-30	2.15-2.20	As Per Unrestricted				50-80	40%	20-40	1.92-2.10
Lw Pure G.M Site ICHmw2	None	60-110	0-10%	50-60	1.58-1.67		N/A**				N/A**		
	Light	60-100	0-10%	50-60	1.43-1.50		N/A**				N/A**		
	Moderate	60-100	0-10%	50-60	1.37-1.48		N/A**				N/A**		
FdLw G.M Site IDFdm2	None	50-70	50%-90%	30-60	1.47-1.49	50-80	70%	30-50	1.44-1.49	60-80	40%	40-60	1.40-1.45
	Light	60-100	0-10%	50-60	1.26-1.35	a) 40-50	70%	30-50	1.19-1.26	40-70	40%	40-60	1.17-1.23
						b) 60-70	70%	20-40	1.19-1.26				
	Moderate	a) 70-100	0%	N/A	1.05-1.16	40-60	70%	20-60	0.86-0.99	50-70	40%	40-60	0.92-1.06
		b) 50-80	10%	60	1.05-1.16								
		c) 50	40%	60	1.05-1.16								
PlFd G.M Site MSdm1	None	80-100	60-90%	30-40	1.78-1.83		As per Unrestricted			60-90	40%	20-60	1.72-1.75
	Light	70-110	0-10%	50-60	1.53-1.62	60-90	70%	20-60*	1.38-1.44	50-80	40%	50-60	1.38-1.48
	Moderate	60-110	0-20%	60	1.36-1.46	a) 70-90	70%	20	1.11-1.22	40-80	40%	40-60	1.14-1.31
						b) 40-60	70%	30-60	1.11-1.22				

* Stand age @ final harvest not to exceed 120 years.

** MAI is not maximized at this residual basal area.

The effects of Armillaria levels were species dependent, and as levels of Armillaria increased the potential MAI decreased dramatically using the same management regime. With light to moderate infection levels of *Armillaria*, in all stand types except pure lodgepole pine, the maximum MAI was obtained by leaving low residual basal area followed by prompt reforestation with less susceptible species. For lodgepole pine, the analysis indicates that a heavier residual basal area after the partial cutting, followed by a shorter time period to the final harvest, may minimize MAI losses to A*rmillaria*. It is speculated that lodgepole pine is more easily infected but succumbs more slowly to *Armillaria* than other species (Don Norris 1996, pers. comm.).
In lodgepole pine/Douglas-fir stands, the MAI decreased by 11% (1.83 m^3/ha/year to 1.62 m^3/ha/year) with light infection and by 20% (1.46 m^3/ha/year) with moderate infection.

Because species susceptibility can vary from one location to another, Hadfield (1984) recommends species selection in *Armillaria*-infected stands based upon which tree species is locally least infected by the disease. The management implications are that root diseases will be perpetuated and worsened by growing only highly susceptible tree species in diseased areas. Regardless of the species selected, early mortality should be expected especially during the regeneration stage because all species are equally susceptible as young seedlings (Don Norris, 1996, pers. comm.).

The *Root Disease Management Guidebook* (B.C. Min. For. 1995c) cautions against using partial cutting systems in root disease infected sites. *However, partial cutting may be a low risk harvest method if certain root disease management strategies, such as alternate species selection, group selection/small patch clearcuts and inoculum removal (e.g.: stump removal after harvesting and push-over harvesting as part of the falling operation) are considered.* Alternate species selection is the most frequently recommended strategy for managing root disease (Hadfield 1984; van der Kamp and Hawksworth 1985; Coates *et al.* 1994; B.C. Min. For. 1995c; Carlson *et al.* 1995; Filip *et al.* 1995; Jay Berube 1996, pers. comm.; Russell Graham 1996, pers. comm; John Townsley, 1996, pers. comm.). This approach includes:

1. removing susceptible species and maintaining resistant species in the overstory or as advanced regeneration; and

2. manipulating the stand at harvesting and regeneration stages to obtain a future crop of resistant species.

Broadcast burning or underburning does not significantly reduce root rot inoculum but it can be effective in reducing the future damage when used to prepare sites for establishing less susceptible species or to prevent the more susceptible Douglas-fir and true firs from becoming established (Hadfield 1984). Inoculum avoidance and biological/chemical control techniques are experimental and not recommended for broad scale implementation at this time.

Low risk stands with respect to *Armillaria* contain significant amounts of healthy, more resistant species in the overstory and have relatively low amounts of the disease expressed as infections. Stands that do not meet the above criteria may be converted to low risk stands over several rotations through specific choice of silviculture system, regeneration techniques, species selection and stand tending activities.

4.2 Effects of Partial Cutting on Wood Flow.

4.2.1 Boundary District

Table 4 and Figure 1 show the comparison of wood flow using the unadjusted and adjusted PROGNOSIS growth curves for the Boundary Forest District. When the unadjusted PROGNOSIS growth curves were substituted for the original VDYP curves, no valid comparisons of the effects of partial cutting management regime could be made (Figure 1, top diagram). The current AAC of 700,000m^3 per year was maintained indefinitely whether clearcutting or partial cutting was employed. The reason for this is the absolute differences in volume between the PROGNOSIS generated curves and the VDYP curves which were used in the TSR. The PROGNOSIS-developed partial cutting curves sometimes estimated yields 46% higher than the corresponding VDYP curves. When the 700,000m^3/yr AAC was imposed on a forest with the majority of stands that had a higher volume than modeled in the TSR, there was no falldown in the wood supply using either clearcutting or partial cutting techniques (Hal MacLean 1996, pers. comm.).

When operational adjustment factors (OAFS) were used to scale the PROGNOSIS curves so that they had the same volumes at age 120 as the original VDYP curves, there was no significant difference in wood flow between clearcutting and partial cutting (Figure 1, bottom diagram). The clearcut scenario showed slightly more wood available in decades 9 and 10 over partial cutting, but no reasons for this effect could be deduced (Hal MacLean 1996, pers. comm.).

When the volume available for partial cutting was limited to 20% of the AAC, to reflect the estimated area available for partial cutting in the TSR, there was no difference in the wood flow in the short or long term between clearcutting and partial cutting. However, the decline in available volume to the long run sustained yield of 620,000m^3 was sooner, beginning in decade 4 compared to decade 10 for clearcutting. These results are due to the methodology used to model partial cutting, and not necessarily due to the effects of partial cutting. The 20% AAC limit was translated into the FSSIM model as a harvesting profile constraint of 20% of the total harvesting land base. This constraint reduces the flexibility in the model to harvest the partial cutting volume from the most appropriate stands or areas and produces a less optimum harvest schedule. The result is a decline of wood availability (Hal MacLean, pers. comm.).

There appears to be sufficient unconstrained mature growing stock available in the inventory to support the current AAC of 700,000m3 per year in the short term regardless if the stands are harvested using clearcutting or partial cutting methods. Because of the availability of growing stock and effects of uncalibrated growth curves, it was decided to forgo further analysis of the effects of root rot for the Boundary Forest District. There were too many factors that would mask the effects of *Armillaria*.

4.2.2 Cranbrook District

The comparison for Cranbrook Forest District was more straight-forward than for Boundary Forest District. The PROGNOSIS curves did not have to be adjusted. The results of the comparisons are shown in Table 5 and Figure 2.

The PROGNOSIS clearcut growth curves produced a slightly higher short and long-term wood flow than the original VDYP curves used in the TSR base case. The existing harvest level was extended for 10 years longer than the TSR base case. The increase in harvest levels is attributed to higher volumes generated for similar timber types using PROGNOSIS compared to VDYP.

The long-term increase is also attributed to:

1. reduced yields of 13% in the TSR base case curves to allow for seed trees that were never harvested or salvaged;

2. the methodology for capping the curves in order to make them acceptable to the FSSIM model.

The PROGNOSIS clearcutting and partial cutting regimes with no root disease had the same harvest level for the first 110 years before diverging and then rising to different long-term levels (Figure 2). The similarity of harvest levels in the short-term is attributed to:

1. The availability of stands that are suitable for partial cutting. The stands did not become available for partial cutting in this analysis until they reached 100 years of age. In reality, the majority of lodgepole pine stands in Cranbrook are younger and are suitable for harvesting before reaching this selected age.

2. The partial cutting regime that was tested. There are other combinations of management regimes (Table 3) that produced higher MAIs than the one modeled. Other regimes could have resulted in a greater difference in effects between clearcutting and partial cutting at both the stand and forest level of analysis.

3. The aggregation of partial cutting timber types into analysis units used in the FSSIM model. Partial cutting growth curves were developed for only a limited number of timber types. These timber types were then aggregated with other timber types (for which partial cutting growth curves were not developed) into analysis units similar to those used in the TSR process, thereby masking the effects of partial cutting.

Table 4. Comparison of TSR base case, clearcutting and partial cutting wood flow scenarios for Boundary Forest District.

Period	Decade start year	TSR	Unadjusted PROGNOSIS Growth Curves		Adjusted PROGNOSIS Growth Curves		
		Base Case/ No Root Disease (m^3/decade)	Clearcut/ No Root Disease (m^3/decade)	Partial Cut/ No Root Disease (m^3/decade)	Clearcut/ No Root Disease (m^3/decade)	Partial Cut/ No Root Disease (m^3/decade)	Partial Cutting Limited to 20% of Land base/ No Root Disease (m^3/decade)
1	1994	7,000,000	7,000,000	7,000,000	7,000,000	7,000,000	7,000,000
2	2004	7,000,000	7,000,000	7,000,000	7,000,000	7,000,000	7,000,000
3	2014	7,000,000	7,000,000	7,000,000	7,000,000	7,000,000	7,000,000
4	2024	7,000,000	7,000,000	7,000,000	7,000,000	7,000,000	6,300,000
5	2034	7,000,000	7,000,000	7,000,000	7,000,000	7,000,000	6,200,000
6	2044	7,000,000	7,000,000	7,000,000	7,000,000	7,000,000	6,200,000
7	2054	7,000,000	7,000,000	7,000,000	7,000,000	7,000,000	6,200,000
8	2065	7,000,000	7,000,000	7,000,000	7,000,000	7,000,000	6,200,000
9	2074	6,300,000	7,000,000	7,000,000	7,000,000	6,300,000	6,200,000
10	2084	5,670,000	7,000,000	7,000,000	6,300,000	6,200,000	6,200,000
11	2094	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000
12	2104	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000
13	2114	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000
14	2124	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000
15	2134	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000
16	2144	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000
17	2154	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000
18	2164	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000
19	2174	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000
20	2184	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000
21	2194	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000
22	2204	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000
23	2214	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000
24	2224	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000
25	2234	5,600,000	7,000,000	7,000,000	6,200,000	6,200,000	6,200,000

Figure 1. Boundary Forest District: Comparison of Clearcutting and Partial Cutting on Wood Flow

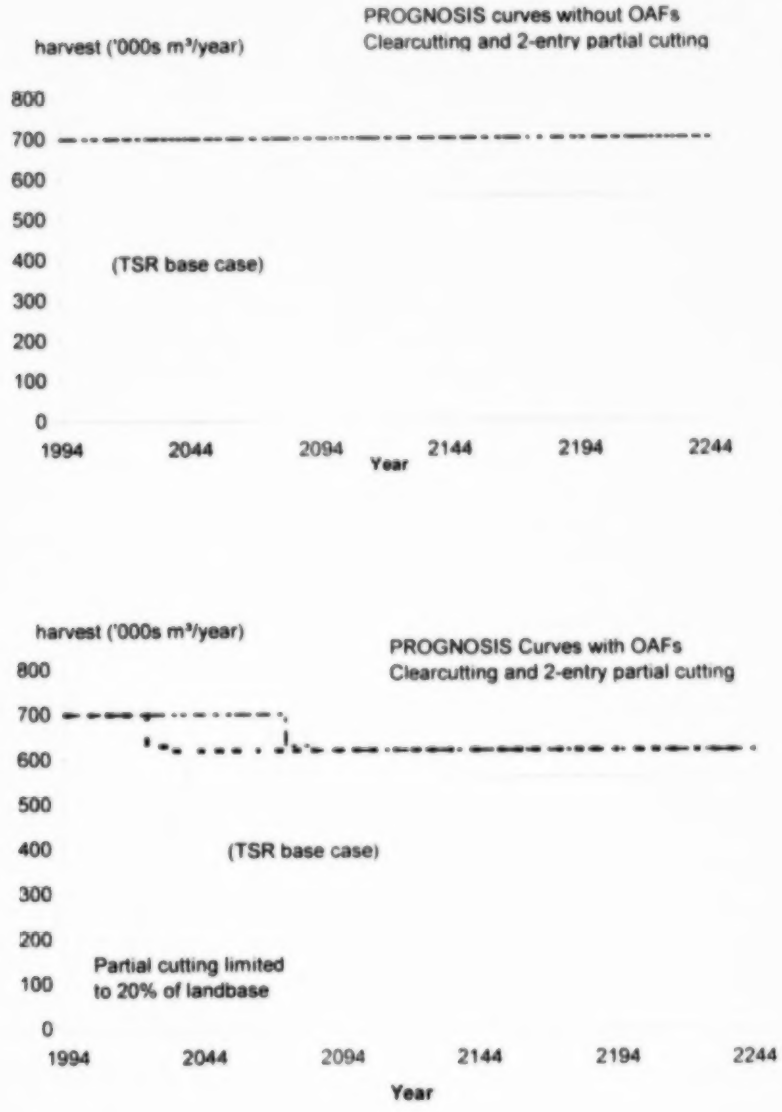
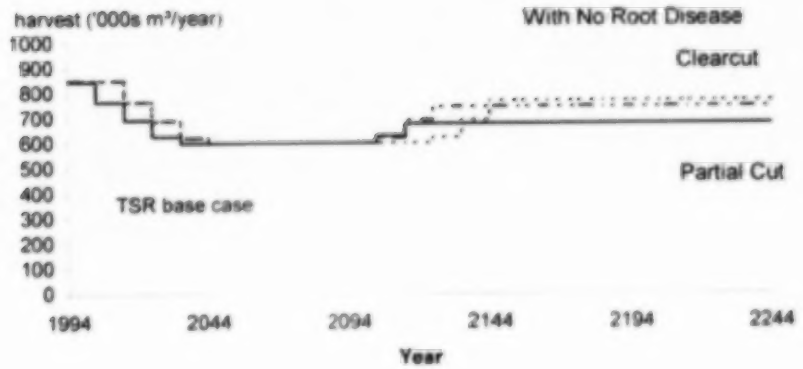
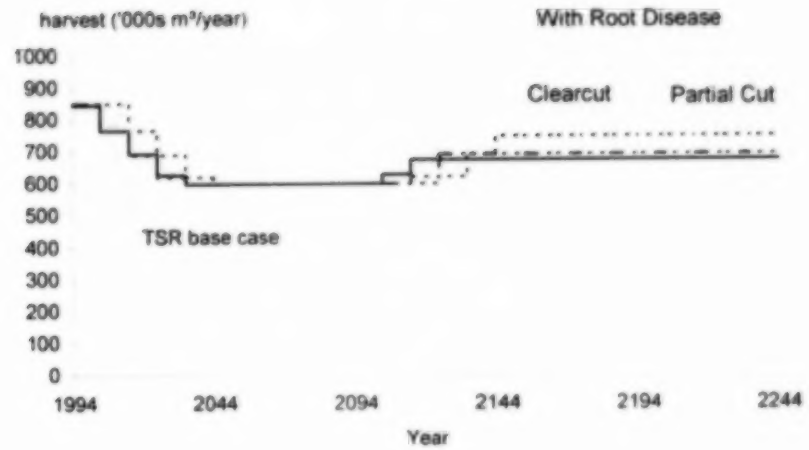


Table 5. Comparison of TSR base case, clearcutting and partial cutting scenarios with various levels of *Armillaria* root disease for Cranbrook Forest District.

Period	Decade start year	Harvest m^3 per 10 year period				
			PROGNOSIS developed growth curves			
		TSR 1 Base Case Clearcutting/ No Disease	Clearcutting / No Disease	Clearcutting / Root Disease	Partial Cutting / No Disease	Partial Cutting / Root Disease
1	1994	8,450,000	8,500,000	8,500,000	8,500,000	8,500,000
2	2004	7,650,000	8,500,000	8,500,000	8,500,000	7,650,000
3	2014	6,920,000	7,650,000	7,650,000	7,650,000	6,885,000
4	2024	6,260,000	6,885,000	6,885,000	6,885,000	6,196,000
5	2034	5,980 ,000	6,196,000	6,196,000	6,196,000	5,980,000
6	2044	5,980,000	5,980,000	5,980,000	5,980,000	5,980,000
7	2054	5,980,000	5,980,000	5,980,000	5,980,000	5,980,000
8	2064	5,980,000	5,980,000	5,980,000	5,980,000	5,980,000
9	2074	5,980,000	5,980,000	5,980,000	5,980,000	5,980,000
10	2084	5,980,000	5,980,000	5,980,000	5,980,000	5,980,000
11	2094	5,980,000	5,980,000	5,980,000	5,980,000	5,980,000
12	2104	6,260,000	5,980,000	5,980,000	6,196,000	5,980,000
13	2114	6,720,000	5,980,000	5,980,000	6,885,000	6,196,000
14	2124	6,720,000	6,196,000	6,196,000	7,400,000	6,885,000
15	2134	6,720,000	6,885,000	6,885,000	7,400,000	6,885,000
16	2144	6,720,000	7,650,000	7,450,000	7,400,000	6,885,000
17	2154	6,720,000	7,650,000	7,450,000	7,400,000	6,885,000
18	2164	6,720,000	7,650,000	7,450,000	7,400,000	6,885,000
19	2174	6,720,000	7,650,000	7,450,000	7,400,000	6,885,000
20	2184	6,720,000	7,650,000	7,450,000	7,400,000	6,885,000
21	2194	6,720,000	7,650,000	7,450,000	7,400,000	6,885,000
22	2204	6,720,000	7,650,000	7,450,000	7,400,000	6,885,000
23	2214	6,720,000	7,650,000	7,450,000	7,400,000	6,885,000
24	2224	6,720,000	7,650,000	7,450,000	7,400,000	6,885,000
25	2234	6,720,000	7,650,000	7,450,000	7,400,000	6,885,000

Figure 2. *Cranbrook Forest District: Comparison of Clearcutting and Partial Cutting on Woodflow.*





In the long-term, the partial cutting PROGNOSIS forecast rises 20 years sooner than the clearcutting forecast. This is possible, in part, because it is permissible to enter stands to be partially cut 20 years sooner than clearcutting (for example at age 100 versus a default minimum harvest age of 120 for some of the stand types). The higher long-term volume for the clearcutting can be attributed to lower productivity at the stand level because of the partial cutting regime that was used. Also, only the stand types initially partially cut are partially cut in the second rotation. Stands that were initially clearcut were also clearcut in the second rotation. For the stands that were initially clearcut, managed stand yield tables were used to project the volumes over time of the regenerated stands.

Clearcutting in stands without root disease and in stands with root disease followed the same wood flow pattern for the first 150 years. However, the long-term wood flow for the root disease scenario was approximately 3% lower (Table 5). This is attributed to the loss in productivity due to the effects of *Armillaria* which only becomes evident after harvesting the stands.

Partial cutting with root disease resulted in a reduction in wood supply in the second decade and reached the lowest level of harvesting ten years sooner than clearcutting with or without root disease (Table 5: Figure 2, bottom diagram). The long-term harvest level was also 7.6% lower than for the clearcut with disease and 10% lower for the no disease scenario. We speculate that the reasons for this are that clearcut stands are regenerated sooner to more disease resistant species and do not have root rot levels increased due to the effects of partial cutting.

This study examined the effects of partial cutting on a very limited number of stands and under only one management regime. Although, in this study, partial cutting did not show significant short-term (i.e. 10 years) wood supply effects compared to clearcutting, mid-term effects in root disease-infected stands were visible in Cranbrook.

Other forest level models can better demonstrate the effects of partial cutting. For example, a study on the impacts of commercial thinning in Kootenay Lake TSA using different modeling assumptions and the CASHFM forest estate model, did show an increase in short-term wood supply. The study showed that a level of 300 hectares per year of commercial thinning may increase the wood supply in the short term by 5-11% with little or no effect in the long term. The increase in the short term reflects the degree to which forest cover constraints are limiting wood flow (Anonymous, 1997). That study did not, however, study the impacts of root disease.

5 CONCLUSIONS AND RECOMMENDATIONS

Clearcutting and seed tree silviculture systems account for approximately 83.5% of the area harvested between 1988 and 1995 in the Nelson Forest Region. Pressure to maintain the harvest levels in the face of mounting constraints requires an increase in the use of partial cutting silviculture systems. The main factors that limit the amount of partial cutting are applicability of the various systems in certain stand types, past experience with various systems, the effects of *Armillaria* root disease, economics and constraints imposed by the FPC and KBLUP.

There is potential to meet the demand for partial cutting in some timber types in constrained areas while still meeting adjacency and other management objectives. Although there is a general consensus that *Armillaria* is present throughout the Nelson Forest Region, the fact that *Armillaria* exists in a stand will not preclude that stand from being harvested and managed. The presence of *Armillaria* however, will dictate the management options available on that site.

Partial cutting silviculture systems should not be considered a panacea as they have limitations. Therefore, clearcutting and seed tree systems can still continue to be used where applicable. The choice of the system depends on management objectives, current stand structure, forest health or other site conditions. Landscape level objectives for forest structure will dictate the pattern of stand structures and silviculture systems that are required.

Partial cutting silviculture systems are suitable in many of the stand types in which they are currently being applied as well as to some types in which they are not being applied. Group selection (and patch clearcutting) followed by shelterwood systems offer the most flexibility in terms of suitable stand types and control of the regeneration and future stand tending activities. Where there are options in the choice of silviculture system, the system that provides the healthiest forest conditions while meeting management objectives in constrained areas should be selected.

Recommendation 1: Partial cutting prescriptions should consider: a) suitability as determined by silvicultural, regeneration and forest health characteristics of the stands; b) maximization of MAI, and; c) wood flow in the management unit. *Group selection and small patch clearcuts, followed by shelterwood systems offer the most flexibility with the lowest risks to regenerating stands.* The choice of silviculture system, site preparation techniques and stand tending activities should all contribute to maximizing the yield and the reduction of risk to *Armillaria*.

Partial cutting may have potential to maintain current harvest levels for a longer period in the short-term. This is because adjacency and other constraints can be addressed while providing increased flexibility in stands that can be harvested. Increases in the short-term and long-term wood supply are not significant as presently modelled by FSSIM.

Recommendation 2: District Managers should examine the historic use of partial cutting and expand their programs where applicable and as necessary in constrained areas, minimizing

risk through root rot surveys and attention to the principles of MAI maximization. Partial cutting should focus on low risk approaches involving *Armillaria*-resistant species and inoculum removal. Group selection and small patch clearcuts are strongly favoured for lowering risk.

Current partial cutting guidelines are vague or do not exist for many stand types or management objectives. Partial cutting expertise needs to be developed and encouraged in the Nelson Forest Region.

Recommendation 3: Regional silviculture systems staff should assume a training and extension function and devote adequate staff time to providing formal and "tailgate" workshops, conducting case studies and publishing a series of example silviculture prescriptions (SP's) that develop partial cutting expertise in the Nelson Forest Region.

Sensitivity analyses indicate that *Armillaria* is a significant risk in partially cut stands and can significantly lower stand MAI.

Recommendation 4: In order to maximize MAI in a partially cut stand, we must know the level of *Armillaria* infection. Recent trials with the present survey systems indicate that the systems cannot differentiate between different *Armillaria* infection levels. This must be corrected at the provincial level by the Forest Health Section to ensure that silviculture prescriptions (SP's) can be correctly developed.

Recommendation 5: The regional forest pathology program should ensure that: a) the Armillaria root disease SOP is finalized with the assistance of the regional soil scientist, site preparation coordinator, incremental silviculturist and the provincial pathologist; b) a regional database is developed for root rot and soil disturbance surveys so that the MAI implications of root disease and pushover logging can be modeled, and; c) the development of the ROTSIM root disease model is supported during the development of PROGNOSIS.

The version of FSSIM used for this report was too simple and inadequate to model the effects of partial cutting on wood flow. The model can be used to determine if there is/is not a wood flow effect using partial cutting versus clearcutting. FSSIM cannot be used to determine specific effects or optimize wood flow based on various combinations of clearcutting, partial cutting or commercial thinning. FSSIM must evolve considerably before it can accommodate the nuances of partial cutting in complex, mixed species stands that are common in the Nelson Forest Region.

Recommendation 6: Use FSSIM as a screening tool to determine if there is or is not an effect of partial cutting on wood flow. If there is no negative effect, then other forest estate models, which can accommodate partial cutting, should be used to demonstrate the effects.

In summary, this is the first time that partial cutting growth curves have been developed using an appropriate stand level model for important timber types in the region. The PROGNOSIS stand model will soon be calibrated for this region and it will be the fundamental growth and yield model for complex partial cutting prescriptions. Some important trends and implications of management regimes have been identified. Partial cutting can be used to maximize MAI at the stand level, provided that appropriate residual basal areas are first established and then the residual trees are removed. Biodiversity and adjacency guidelines for residual basal area retention can be achieved using partial cutting silviculture systems with little or no reduction in MAI versus clearcutting systems. Clearcutting and partial cutting growth curves can be developed using PROGNOSIS and easily incorporated into the FSSIM harvest forecast model. However, the current FSSIM model does not demonstrate the effects of partial cutting on wood flow well at this time and requires structural modifications before it can be used for this purpose.

6 PERSONAL COMMUNICATION

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APPENDIX A

Appendix A. Summary of partial cutting literature review. "Low Risk" stand types are Douglas fir, western larch, lodgepole pine and Ponderosa pine. The other stand types are included because they are common in parts of the Nelson Forest Region. It should be noted that the timber types almost never occur as single species.

Species	Silvicultural System				
	Seed Tree	Shelterwood	Selection	Commercial Thin[1]	Comments
Douglas-fir	• can be used in ICH and MS (Schmidt 1990) • density ranges between 8-80 sph (Vyse *et al.* 1991) • not feasible for natural regeneration in dry-belt Douglas-fir (Weetman and Vyse 1990) • remove overstory on snowpack or when regeneration is less than 1 m tall (MoF 1992)	• acceptable where Douglas-fir is climax species (Schmidt 1990) • Weetman and Vyse (1990) do not recommend this systemfor natural regeneration in wet belt Douglas-fir stands • DeLong (1994) recommends 5-25 m2/ha in ICHmk1 and ICHmw1 • residual density 40-200 sph (Vyse *et al.* 1991) • residual basal area 5-25 m2/ha (Vyse *et al.* 1991)	• single tree selection common in dry-belt IDF (Vyse *et al.* 1991) • where Douglas-fir is climax tree or group selection are appropriate (Schmidt 1990) • residual basal area 15-25m2/ha (Vyse *et al.* 1991) • quotient value 1.3-1.7 (Vyse *et al.* 1991) • volume retained 30-75% (Vyse *et al.* 1991) • group selection suitable in ICH (Smith and Smith. 1994)	• recommended in dry-belt sites to increase growth and may provide some degree of protection from spruce budworm attacks (Vyse *et al.* 1991)	
Western larch	• recommended (Weetman and Vyse 1990. Helms and Lotan 1988)) • not often appropriate for species conversion because of inability to predict good seed crops • used in Okanagan National Forest in complexes similar to MSdm1 at residual density ranges between 8-15 sph and residual basal area 3.5-4.5m2/ha (Townsley pers. comm. 1996)	• feasible (Weetman and Vyse 1990. Helms and Lotan 1988) • not often appropriate for species conversion because of inability to predict good seed crops • two-cut shelterwood system recommended over 3-cut • on exposed sites, offers greatest protection for new seedlings (Schmidt and Shearer 1990) • can provide thermal cover in areas with risk of frost damage (Helms and Lotan 1988) • provides least opportunity to control dwarf mistletoe in heavily infected stands (Schmidt and Shearer 1990) • can lead to deterioration of vigor in over-mature stands (Schmidt and Shearer 1990)	• group selection is appropriate (Helms and Lotan 1988) • square or rounded openings are preferable to narrow strips or openings with undulating boundaries for dwarf mistletoe infections (Schmidt and Shearer 1990) • remove infected perimeter trees and advanced regeneration (Schmidt and Shearer 1990)	• stands up to 50 years old have shown diameter increase response to thinning (Schmidt and Shearer 1990) • where dwarf mistletoe infection intensity is light to moderate, the benefits of thinning on tree growth outweigh the adverse effects of stimulation of dwarf mistletoe plants ((Filip *et al.* 1995) • previously unmanaged larch stands should be thinned from below rather than from above to decrease residual tree mortality and breakage to snow and ice (Filip *et al* 1995)	• site preparation is required (Thompson 1995, Graham *et al.* 1995) • very shade intolerant; requires sufficient light for establishment and growth (Helms and Lotan 1988) • mistletoe infected overstory trees should be removed as soon as possible after seedling establishment (Wyman and Shearer 1990) • larch usually only a minor component on dry south and west slopes due to drought (Schmidt *et al* 1976) • northeast and -west slopes most favorable for seedling survival (Schmidt *et al* 1976)
Lodgepole pine	• not recommended (Weetman and Vyse 1990) • windthrow can be a problem (Schmidt and Alexander 1985) • this is a predominant stand type in NFR for this system (Hawe 1997)	• not recommended (Weetman and Vyse 1990) • can be used where windthrow is not a problem and additional shade is required for regeneration (Schmidt and Alexander 1985)	• only group selection is appropriate (Schmidt and Alexander 1985) • patch cutting can create a mosiac of age and size classes that reduces the area susceptible to mountain pine beetle at one time (Amman and Safranyik 1985)	• thinning to 247 sph or 18.4 m2/ha has reduced mortality to bark beetles in Washington, Wyoming and Montana. MAI can be reduced if stands are thinned to this level too early (Amman and Safranyik 1985) • done on a limited basis in Invermere, Cranbrook and Boundary in 60-80 year unmanged dense stands • residual density ranges between 400-500 sph to 800-1000sph where greater risk of windthrow. Time to final harvest and tree response is unknown	• removing beetle infested trees only is not a silvicultural system
Ponderosa pine	• recommended (Weetman and Vyse 1990) • this is a predominant stand type in NFR for this system (Hawe 1997) • can be used in diseased stands only if residuals are removed before they can seriously infect regeneration (Hawksworth and Shaw 1988)	• feasible (Weetman and Vyse 1990) • have been used in U.S. in stands similar to IDFdm2 to obtain ponderosa pine or larch regeneration within 5 years (Townsley pers. comm. 1996) • residual basal areas used are 9-13 m2/ha on south slopes and 5-11 m2/ha on north slopes (Townsley pers. comm. 1996)	• not feasible (Weetman and Vyse 1990) • in the Okanagan National Forest uneven-aged management is practiced in environments similar to PPdh1, PPdh2 and IDFdm1 (Townsley pers. comm. 1996) • residual basal area 8.1 - 12.7 m2/ha and q-value of 1.1 - 1.2 (Becker 1995) • residual basal area 11.5 - 16.2 m2/ha and q-value of 1.1 - 1.4 in IDF and MS for uneven-aged management (Fiedler *et al.* 1988)		• planting is frequently done to augment episodic natural regeneration and to ensure short regeneration delays
Western hemlock	• not recommended (Weetman and Vyse 1990) • not recommended because of over-dense regeneration and windthrow risk (Ruth and Harris 1979)	• not used in interior stand types and little is known and therefore is not considered low risk	• windthrow can be a problem and removal of more than one-third of the basal area is not recommended (Ruth and Harris 1979) • group selection suitable in old-growth cedar-hemlock stands in ICH (Smith and Smith. 1994)		
Spruce - ESSF	• little information is available about the success of seed trees • density 9-25sph (Coates *et al.* 1994) • residual basal area .7-1.4m2/ha (Coates *et al.* 1994)	• not feasible in old growth but recommended in second growth stands (Weetman and Vyse 1990) • 50 - 110 sph, 30 - 40% basal area removal, 9-17 m2/ha residual basal area (Coates *et al.* 1994) • seedbed most suitable for 5 years (Coates *et al* 1994)	• feasible in old growth and second growth stands (Weetman and Vyse 1990) • group selection is suitable for all types of stand conditions (Alexander 1987) • width of cut strip ranges between 15-137 m; maximum opening size is 1 to 6 tree lengths (Alexander 1987)	• salvage dead, obviously infected, symptomatic as well as trees within 10 m radius of infected trees, except in extensively infected stands where commercial thinning is not recommended (Coates et al. 1994)	• mechanical site preparation is recommended to produce adequate natural regeneration (Coates *et al.* 1994) • use progressive strip cutting into prevailing wind if blowdown is a problem (Coates *et al.* 1994)
Spruce - montane	• feasible in second growth stands (Weetman and Vyse 1990)	• feasible in second growth stands but not feasible in old growth (Weetman and Vyse 1990)	• not feasible in old growth and feasible in second growth stands (Weetman and Vyse 1990)		

[1] Although commercial thinning is not a silvicultural system it has been included here as it is a treatment as part of a silvicultural system.